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C. C. Ruchhoft, et al

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STUDIES OF SEWAGE PURIFICATION. IX. TOTAL PURIFICATION, OXIDATION, ADSORPTION AND SYNTHESIS OF NUTRIENT SUBSTRATES BY ACTIVATED SLUDGE.

By
C. C. Ruchhoft, Principal Chemist; C. T. Butterfield, Principal Bacteriologist; P. D. McNamee, Assistant Chemist and Elsie Wattie, Assistant Bacteriologist,
U.S. Public Health Service
Stream Pollution Investigations,
Cincinnati, Ohio.

The first phenomenon taking place when a nutrient substrate such as sewage is aerated with activated sludge has been described (Parsons[1], Theriault[2], Heukelekian[3], and others) as the clarification stage. The term clarification has been defined as the removal of carbonaceous and nitrogenous organic matter in all states of dispersion (suspension, colloidal and true solution) from the substrate by the sludge as a result of coagulation, adsorption and other mechanisms. A number of theories to explain the mechanism of clarification have been proposed and have been recently reviewed by Theriault[2]. Theriault[4][5][6], has also proposed a new biozeolitic theory. These theories will not be discussed here. The clarification process is generally considered to be very rapid, equilibrium being reached in 30 to 40 minutes. This stage is followed by what has been described as reactivation, or restoration of the powers of clarification. The present paper is a further presentation of the results of a study of clarification and reactivation phenomena of the activated sludge process.

In three earlier papers[7][8][9] of this series, data upon the oxidation rates of nutrient substrates aerated with activated sludge during the clarification stage have been obtained by the "difference" method. In these papers data were presented on the

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rate of reduction of the biochemical oxygen demand of the organic matter in the substrates that resulted during portions of the first 24-hour aeration period with activated sludge. The studies showed definitely that rates of biochemical oxidation of substrates by activated sludge are much higher than the rates obtained normally in polluted streams or in dilution bottles. The tremendous bacterial populations containing oxidation enzymes, present and active, when fresh nutrient substrates are mixed with activated sludge was proposed as the explanation of the high rates of biochemical oxidation that are observed.

It is the purpose of this paper to present data on the total removal of biochemical oxygen demand (B.O.D.) of nutrient substrates by activated sludge and to show what portion of the total removal may be accounted for by oxidation. The demonstration of the portion of the total B.O.D. removal that is the result of oxidation has not been made before. The removal of organic matter as measured by the reduction of the total carbonaceous oxygen demand (L value) of the substrate will be defined here as the total B.O.D. removal or total purification. The quantity of oxygen utilized by the sludge - nutrient substrate mixture as a result of the addition of the substrate (as has been described[8][9]), is defined as the B.O.D. of the substrate removed by oxidation. The difference between the total B.O.D. removal and the oxidation of the substrate will be referred to here as the net adsorption and synthesis. It should be understood, however, that the term net adsorption and synthesis is used simply for convenience and that this term includes also any B.O.D. removal accomplished

by coagulation, hydrolysis and any possible mechanisms other than oxidation.

Experimental Methods

Sludge. Data will be presented showing the total purification and oxidation of substrates when aerated in the presence of pure culture and plant activated sludges. The pure culture sludges used were identical with those already described(8). The plant sludges were obtained from the north side plant at Lancaster, Pa., and from the experimental plant at this station.

Nutrient Substrates. Synthetic sewage of the composition given in an earlier paper(8) of this series was used in experiments with both pure culture and plant activated sludge. This material simulated sewage in its biochemical oxygen demand value but had no suspended detritus and contained all of the nutrient material in true colloidal or soluble form. It contained peptone and meat extract as nutrients besides small quantities of urea, disodium-hydrogen phosphate and other inorganic salts usually found in sewage. Domestic sewage filtered through cotton was used in experiments with normal activated sludge and after sterilization also with the pure culture sludge. The domestic sewage was heat sterilized (15 lbs. steam pressure for 20 minutes) when used in experiments with pure culture sludge. Previous experimental work(8) indicated that heat sterilization altered the condition of the sewage less than other sterilization methods and also that this sterilized sewage was as suitable a substrate for activated sludge development as the sewage before sterilization.

Dilution Water. The quarter strength phosphate buffered[10] (Formula C) water was used for all dilution purposes in these experiments.

General Procedure. The procedure followed in these experiments has been described in detail[8]. Briefly it consisted of aerating simultaneously and at approximately the same rate, six liters of sludge-nutrient substrate mixtures in one large bottle and a liter of sludge-dilution water mixture and a liter of sludge-nutrient substrate mixture in two separate closed aeration bottles. The total B.O.D. removal was determined by periodic examination of the substrate in the large bottle and the extent of oxidation was followed in the closed bottles.

In order to save the time required to separate the sludge from the supernatant by settling and to reduce the quantity of sample required, each aeration mixture sample taken to determine total B.O.D. removal was first filtered through No. 1 Whatman paper, and diluted portions of the filtrate were then immediately prepared for incubation. This procedure, used in experiments with synthetic sewage, did not remove any oxidizable material which would not have been removed by settling for the synthetic sewage nutrients were entirely in colloidal and soluble form. In the experiments with cotton filtered sewage it is possible that the procedure may have indicated in some cases a slightly higher organic matter removal than would have been obtained by settling after short periods of aeration.

However, comparative B.O.D. tests on filtered supernatant and

supernatant after one hour settling, following 24 hour aeration periods of sterile sewage and synthetic sewage with pure culture activated sludge, indicated that there was very little difference between the two procedures. These computed L values as derived from B.O.D. results at various periods of incubation are tabulated below:

Experiment Number	Substrate Feed	Initial L Value of Substrate		L Value of Substrate after 24 hours		Percentage Reduction	
		Settled	Filtered	Settled	Filtered	Settled	Filtered
1	Sterile Sewage	279	277	33.7	21.8	87.9	92.1
2	Sterile Sewage	517	515	49.0	56.8	90.5	88.9
3	Synthetic Sewage	—	400	36.7	34.2	90.8	91.5

The filtration procedure was, therefore, adopted for all experiments as being the best method of removing the sludge particles quickly in order to obtain an estimate of the total quantity of nutrient material remaining in the substrate.

PURE CULTURE ACTIVATED SLUDGE EXPERIMENTS

The pure culture sludges represent the simplest activated sludge system because they contain the flocs of only one bacterial species and no plankton or protozoa. Accordingly, the data on the experiments performed with pure culture sludge will be presented first. In Table 1 are presented the basic data of biochemical oxygen demands of the nutrient substrates used in all our experiments with pure culture sludge. The initial B.O.D. of the mixture of nutrient substrate and remaining sludge liquor was calculated from the B.O.D. of the old supernatant removed and the B.O.D. of the nutrient substrate added. The B.O.D. of the supernatant after various periods of aeration was determined by the dilution method. Using the theoretical formula for rate of carbonaceous oxidation of sewage at 20°C. [$y = L\,(1-10^{-kt})$] with $k = 0.1$ and each B.O.D. value of the supernatant shown in Table 1, an L value or total carbonaceous oxygen demand was calculated. However, B.O.D. observations for long incubation periods, where examination showed nitrification, were not included in calculations of the L value. The means of the L values calculated from all incubation time

B.O.D. observations for the supernatant after each aeration time are shown in Table 2.

From the data in Table 2, the percentage reduction in the total carbonaceous oxygen demands (L values) of the substrates obtained after various periods of aeration with pure culture sludge, were calculated and are shown in Table 3. Curves showing the mean percentage reduction of these L values for the experiments with sterile sewage and with synthetic sewage substrates aerated with pure culture sludge are shown in Fig. 1. Curves showing the maximum and minimum substrate L value reductions obtained on both sterile sewage and on synthetic sewage are shown in Figure 2. These curves indicate that the L value of the substrate was removed very rapidly by pure culture activated sludge which had been developed on either sterile sewage or on synthetic sewage. The fact that there is a consistent difference between the curves representing the L value removed in the synthetic sewage and in the sterile sewage experiments may be explained in whole or in part by chemical as well as physical differences between the two substrates, but the possibility cannot be ruled out that part of the observed difference may be a reflection of an unequal response of the sterile sewage and synthetic sewage substrates to the filtration technic. However, it is believed that future research will probably show that most of the difference may be ascribed to the chemical and physical differences between the two substrates. It will be noted from Table 3 and the Figures 1 and 2, that the total purification was less rapid with synthetic sewage, that is, in a substrate in which all of the nutrient material was in colloidal or true solution.

As the larger suspended particles would be removed from sewage by filtration through paper, the sewage purification, as illustrated by these curves, might be criticized as being too rapid due to the filtration employed to separate the supernatant from the sludge before the B.O.D. tests were made. It has been shown (3) (11)

that suspended matter is easily removed by aeration of sewage followed by sedimentation and more easily by aeration in the presence of activated sludge. Also, as stated previously, comparative tests on supernatants after filtration and after settling showed no material differences. It is believed, therefore, that the filtration, introduced to separate the sludge quickly, did not alter materially the B.O.D. removal results in the experiments employing normal sewage.

The quantities of oxygen used to oxidize the nutrient substrates in the experiments with pure culture sludge are shown in Table 4. The method of obtaining these data has been described(8) in detail and need not be repeated here. Table 5 shows the data of Table 4 computed to percentages of the initial L values of the supernatant. These results represent the proportion of the substrate L values oxidized in successive periods. In Figure 3 are representative curves illustrative of the rate of reduction of the L value of the substrate produced by oxidation. It should be noted that between 27 and 40 percent of the L value of the substrate has been oxidized in 5 hours aeration and that these figures increase to about 40 to 60 percent at the end of 24 hours. This shows that with these activated sludge systems, a greater proportion of the L value of the substrate was satisfied in the first 5 hours than is satisfied in the first day under normal biochemical oxidation (20.5 percent with a k of .1 at 20°C.).

Purification by Oxidation

When the percentages of the L value of the substrates that are oxidized as given in Table 5, are divided by the corresponding

percentages of total purification, as given in Table 3, the [illegible] fractions of the total purification that have been accomplished by oxidation are obtained. The results of these computations are shown in Table 7. The mean percentage of the total carbonaceous purification that is accomplished by oxidation for the synthetic and sterile sewage experiments are plotted in Figure 4. These data indicate that, with pure culture activated sludge (developed by one species of bacteria rather than a grossly mixed culture) an average of 16 and 21 per cent of the L value removed during the first half hour was the result of oxidation. These percentages increased rapidly and at the end of 5 hours, an average of about 35 and 43 per cent respectively of the total purification of sterile sewage and of synthetic sewage was the result of oxidation. The data definitely indicate that biochemical oxidation is a factor of major importance to the clarification stage of these activated sludge systems.

Net Adsorption and Synthesis.

As the percentage of the L value of the substrate that has been removed and the percentage that has been oxidized are given in Tables 3 and 5 respectively, it is necessary only to subtract the percentages in the latter table from the corresponding percentages in the former to obtain an estimate of the percentages of purification that were the result of net adsorption and synthesis. The net percentages of the L value of the substrate that is removed by adsorption and synthesis, computed in this way, are shown in Table 6. In Figures 5 and 6 are shown the total purification, oxidation and net adsorption and synthesis curves for ex-

periments 9 and 11 with sterile sewage and with synthetic sewage respectively. These two figures illustrate the proportions of the total purification assignable to oxidation and to net adsorption and synthesis which may be expected to occur during the first ten hours of aeration with pure culture sludges. Figure 7 shows the mean net adsorption and synthesis curves for sterile and for synthetic sewage aerated with pure cultures.

NORMAL ACTIVATED SLUDGE EXPERIMENTS.

The experiments with normal (i.e. grossly mixed cultures) activated sludge were conducted in exactly the same way as those with pure culture sludge. Activated sludge from the north plant at Lancaster, Pa., was used in the first eight experiments. Experiment 9 consisted of a series of tests made on sludge from our experimental plant during the development of activated sludge. The details of experiment 9 have been described[9] and need not be repeated.

The base data showing the biochemical oxygen demands of the supernatants in this series of experiments are given in Table 8. The mean total carbonaceous oxygen demands (L values) were calculated from the data in Table 8 in the manner described above. These calculated data are presented in Table 9. The percentages of reduction of the total carbonaceous oxygen demands were calculated as for the pure culture experiments. These percentages are shown in Table 10.

The quantities of oxygen used to oxidize the nutrient substrates in these experiments are given in Table 11. With these

quantities and the initial total carbonaceous B.O.D. (L value) of the substrate the percentages of the L value oxidized were calculated as shown in Table 12.

The asterisks in Tables 11 and 12 indicate that in experiments 4, 8 and 9-S9, nitrification of the substrate was underway at the completion of the experiments when examinations for nitrite and nitrate were made. As examinations for nitrite and nitrate had not been made earlier it is not possible to tell when the nitrification began. It seems reasonable to assume that in these three experiments with actively nitrifying activated sludge that the nitrification of the substrate began between the first and third hour of aeration. Consequently the oxidation values given in Table 11 for these experiments should be reduced by the quantity of oxygen required to produce the nitrites and nitrates present, as the observations on total purification were confined to the carbonaceous stage. Corrections for nitrification could not be made in these experiments because of the lack of the intermediate nitrite and nitrate data. The results of these experiments are retained to demonstrate the wide differences in the purification obtained under these conditions even though the total purification and oxidation in such cases may not be strictly comparable. This complication did not enter into the pure culture sludge experiments because the cultures employed were incapable of oxidizing ammonia nitrogen. In all of the normal activated sludge experiments, except the three mentioned above, nitrites and nitrates were not found in the substrate at the completion of

the aeration period and consequently all of the oxygen was utilized in oxidizing carbonaceous material. In these experiments, therefore, the total purification and oxidation data are as comparable as in the pure culture sludge experiments.

The net percentages of the L value of the substrate removed by adsorption and synthesis (obtained as above for pure culture sludges) are given in Table 13. The percentages of L value removal accomplished by total purification, by oxidation and by net adsorption and synthesis for a number of experiments with normal activated sludge have been plotted in Figures 8 to 13. For this presentation the experiments were selected to illustrate the effects of some of the factors which influence the purification mechanism.

In Experiment 1 a sewage with an L value of 233 p.p.m. was aerated with a sludge of 4610 p.p.m. of suspended solids. The results plotted in Figure 8 show that total purification was very rapid, 72.4 per cent of the L value being removed in 0.5 hour and over 90.0 per cent in 3 hours. The L value reduction produced by oxidation was 5.9 per cent in 0.5 hour. This rapidly increased to 57.4 per cent in 5 hours. The net adsorbed and synthesized results reached a maximum of about 66.5 per cent in 0.5 hour and then dropped rapidly, falling below the percentage oxidized after about 4.0 hours. After 24 hours 74.3 per cent of the L value had been oxidized and only 19.5 per cent remained as adsorbed and synthesized material. As it seems reasonable that most of the biochemical synthesis accompanying bacterial multiplication had

been completed before the 24 hour period, and that such synthesis might be estimated at from 5 to 10 per cent of the L value, this would leave 9.5 to 14.5 per cent of the material removed from the substrate still adsorbed or coagulated in the sludge after 24 hours. The results of experiment 1, just discussed, illustrate the activated sludge purification mechanism when a large quantity of non-nitrifying activated sludge is given a normal quantity of nutrient substrate.

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The results of experiment 2 illustrate the mechanism of purification when a small quantity of activated sludge (1000 p.p.m. suspended solids) is dosed with a substrate having a rather high (389 p.p.m.) L value. The purification results as plotted in Figure 9 for this experiment are quite different from those shown in Figure 8. In this case the total purification is only about 40.7, 62.9, 66.5 and 89.2 per cent of the L value after 0.5, 1.5, 3 and 10 hours respectively, although in 24 hours a high value of 95 per cent was reached. The percentages of oxidation of the L value are also much lower than in experiment 1, being 1.0, 6.9, 12.3 and 31.5 after 0.5, 1.5, 3 and 10 hours. Consequently the net adsorbed and synthesized results attain a value of 56.0 per cent after 1.5 hours, after which this value slowly increases reaching a maximum of about 60 per cent at about the 5th hour and then falls very slowly to about 58 per cent in 10 hours. After 24 hours of aeration about 50 per cent of the L value is still retained as adsorbed and synthesized materials. In this case the percentage oxidized has not reached 50.0 at the end of the 24 hour period. This may be interpreted as the result of an over-

dose of nutrient material for the quantity of sludge used in this experiment.

The results of experiment 3 are shown plotted in Figure 10 and illustrate an intermediate condition between those of experiment 1 and 2. In this experiment the total purification is more rapid than in experiment 2 and very similar to that observed in experiment 1. The percentage oxidation results are considerably lower than those of experiment 1 and considerably higher than were observed in experiment 2. As a consequence, the net adsorbed and synthesized results reached a maximum of about 70 per cent at the end of the 1.5 hour period and then receded rapidly, falling below the percentage oxidized by the tenth hour. It seems apparent from the results presented in these three figures (8, 9 and 10) that the aeration time required for the percentage oxidation to exceed the percentage net adsorbed and synthesized is an index of the adsorption-oxidation balance. A proper adsorption-oxidation balance is essential for the satisfactory operation of an activated sludge system.

At present the optimum proportion of oxidation to net adsorption and synthesis for any practical aeration time is unknown. It would seem from these experiments that Figure 10 might illustrate a system with an approximately optimum adsorption-oxidation equilibrium.

The data obtained in two experiments in which the sludge actively nitrified the substrate during the 24 hour aeration period are plotted in Figures 11 and 12. For reasons explained above no

corrections for nitrification were made. It is possible that nitrification did not start until the third or fifth hour of aeration in which case the carbonaceous oxidation and adsorption relationships are about as indicated in the figures for the first three hours. It will be noted that the time at which the percentage of the substrate organic matter oxidized exceeds the percentage not adsorbed and synthesized in these experiments is much shorter than in experiments 1, 2 and 3 where nitrification had not been initiated. It seems reasonable to conclude that in experiments 4 and 8 most of the total purification of the substrate could be accounted for by oxidation by the end of the fifth hour of aeration and that the proportion of purification resulting from oxidation was higher than in the first three experiments. It is also noted in experiments 4 and 8, with active nitrification, that the proportion of total purification resulting from adsorption and synthesis rapidly becomes negligible. Further studies on the course of total purification, carbonaceous oxidation, nitrification, and adsorption and synthesis of substrates aerated with nitrifying sludges are needed to interpret more intelligently the clarification phenomenon in such systems.

The data obtained in experiment 5 with a synthetic sewage substrate and normal activated sludge are plotted in Figure 13. In this figure the curves are somewhat similar to those in Figure 9 illustrating a case of overloading. But in this case the rate of total purification was much lower than in any of the experiments with domestic sewage. In fact, this rate is also very much lower than that obtained with similar substrates aerated with pure culture

sludges.

The substrate oxidation rates with synthetic sewage in experiments 5 and 6 are similar to those with domestic sewage for the first four hours. Consequently, the failure of these sludges to remove the carbonaceous demand of colloidal and soluble material at a higher rate cannot be ascribed to a failure of bacterial oxidation. The proportion of the L value of the substrate to the quantity of sludge was even lower than this proportion in the pure culture sludge experiments. The results of experiments 5 and 6 in the normal activated sludge series indicate that such sludge does not have as great a capacity for removing organic matter from colloidal or true solution as does pure culture sludge. This may be interpreted as evidence indicating that the larger quantity of inert inorganic or mineral matter, which normal activated sludge always contains, reduces the capacity of the active bacterial surfaces for removing colloidal and soluble organic matter.

The percentages of the net adsorption and synthesis of the substrate L value obtained in a number of the tests made in experiment 9 are presented in Figure 14. The four curves in this figure defining the rate of change in the percentage of the L value removed by adsorption and synthesis, illustrate the change in the form of the curves that takes place during the development of a good activated sludge. The first test (S1) was made after the aeration tank had been operated on the fill and draw principle for three days and 182 p.p.m. of sludge as suspended solids were present. The curve representing the net proportion of L value

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of the substrate adsorbed and synthesized for S1 has the same form as the total purification curve. The fourth test (S4) was made 28 days after aeration had been started and 1188 p.p.m. of sludge as suspended solids were present. The net adsorption and synthesis curve for this test had changed form considerably from the first test and it will be noted that it reached a maximum of about 63.8 percent and in 1.5 hours after which the percentage slowly dropped to 55.4 in 24 hours. In every test thereafter (S6, S9) a maximum point in the net percentage adsorbed and synthesized was reached at about the 0.5 to 1.5 hour aeration time and from this point on the values decreased. The maximum rate of reduction in the percentage not adsorbed and synthesized values was observed in the ninth test (S9) in which a small quantity of nitrate was found at the end of the experiment. The change in the form of these curves is ascribed to the increasing quantity of adsorbing surface and to the increasing capacity of the sludge to oxidize substrate during the early hours of aeration. Data on the development of the oxidizing capacity of the sludge have been presented in greater detail in an earlier paper. (9).

The proportions of substrate L value reductions produced by oxidation when the substrate is aerated with non-nitrifying sludge have been calculated and are shown in Table 14. These data indicate again, as was the case with pure culture sludge, that oxidation is an important factor in B.O.D. removal with activated sludge. There is however, a considerable variation in the percentage of total purification accomplished by oxidation. After aeration of settled sewage substrates with normal activated sludge for half

an hour from 2.45 to 23.7 percent of the total observed purification was accomplished by oxidation. After 1.5 hours these values increased to 11.0 to 31.6 percent and in 5.0 hours to 22.7 to 61.5 percent. The data indicate that at the temperature of the experiment (20°C.) the percentage of total purification produced by oxidation varied with the condition of the sludge, with the dispersion and chemical composition of the substrate, and with the proportions of sludge and substrate in the mixture.

Discussion

These experiments have indicated the proportions of total removal of the carbonaceous biochemical oxygen demand of a substrate which may be credited to oxidation and to net adsorption and synthesis respectively when various conditions obtain. Great differences in the ratio of the extent of oxidation to the net adsorption and synthesis occurred under conditions of underdosing and overdosing. Additional experiments, which are not described here, have shown the effect of prolonging these conditions on the activated sludge mechanism. It is certain that the quality and dosing rate of the substrate must be such as to promote an optimum oxidation, net adsorption and synthesis equilibrium for the continued success of the activated sludge process. If this is not done the efficiency of the process falls and eventually unexpected and formerly unexplainable failure results.

These experiments suggest that, although sludge reaeration is often resorted to as an activated sludge corrective measure, this is not always the proper procedure. A number of cases might be

mentioned where sludge reoeration was harmful because the bacteria were not maintained in a state of activity for lack of food and the oxidation adsorption equilibrium was upset. In general, it would appear that long aeration periods should be avoided when weak sewages are being treated. The data indicate that the ratio of sludge to sewage and the aeration period must be carefully adjusted to maintain the sludge in a state of optimum activity for maximum B.O.D. removal and economical operation. As long as sufficient air is used to keep all of the sludge suspended and dispersed throughout the liquor and to satisfy the oxygen requirements of the aeration mixture, the exact quantity is unimportant from the standpoint of sludge adsorption and oxidation efficiency. From the economic standpoint, therefore, the air should be adjusted to the minimum necessary to maintain the above conditions.

Summary and Conclusions.

Two series of experiments have been performed, one with activated sludges developed by a pure culture of bacteria and one with normal activated sludge composed of grossly mixed bacterial species, including plankton. Some experiments with domestic sewage (as a substrate) and some with synthetic sewage, were carried out in each series. Each experiment was arranged so that estimations of the removal of the total carbonaceous oxygen demand (L value) of the substrate and also of the oxidation of the L value of the substrate were obtained simultaneously. The proportion of the L value of the substrate removed by oxidation and by net adsorption and synthesis and the total removal have been calculated for each experiment from the data obtained. The results for the proportions

of purification of the substrate L value accomplished by those various mechanisms during the clarification stage of the activated sludge process have been plotted for a number of representative experiments. The following conclusions appear to be warranted by the results obtained.

1. There is a remarkable similarity between the purification accomplished by these mechanisms with both pure culture and normal activated sludges. This seems to justify the conclusion that the clarification mechanism of normal activated sludge is essentially the same as with the biologically simple pure culture sludge.

2. The rate of removal of the L value (total carbonaceous B.O.D.) of the substrate is very high for the first half hour and this high rate may continue for an hour and a half or even three hours. From 80 to 95 percent of the L value of a sewage substrate can be removed in five hours aeration with such sludges. The quantity and quality of the sludge influences the rate and extent of total purification accomplished in a given time.

3. The synthetic sewage used in these experiments contains no suspended matter and has undoubtedly a somewhat different chemical composition than sterile sewage. The fact that activated sludge reduced the L value of sterile sewage more rapidly than the L value of synthetic sewage indicates, therefore, that either the state of dispersion or the chemical composition or both may be factors which influence the L value reduction of substrates. Nutrients in soluble form seemed to be more rapidly removed by pure culture sludge than by normal activated sludge.

4. The proportion of the L value reduction of the substrate

that is actually oxidized varies from about 2.5 to 30 per cent in 30 minutes and these values are increased to 30 to 60 per cent after 5 hours aeration. These variations depend upon the quality and quantity of both sludge and substrate in the aeration mixture. From these results it must be concluded that biochemical oxidation is a factor of major importance to the success of the purification phenomenon.

5. The percentage of the L value removed from the substrate as a result of net adsorption and synthesis (all mechanisms other than oxidation) increases rapidly from the start for from 0.5 to 3.0 hours. During this period a maximum of about 50 to 70 per cent of the L value is removed by adsorption and synthesis. After the maximum point is reached the net percentage of the L value removed by adsorption and synthesis decreases. The rapidity of this decrease varies considerably in different systems and apparently depends to a great extent upon the oxidation mechanism.

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TABLE 1.

B.O.D. OF SUPERNATANTS WHEN NUTRIENT SUBSTRATES ARE AERATED IN THE PRESENCE OF PURE CULTURE ACTIVATED SLUDGE.

Experiment No.	Suspended Solids P. P. M.	Nutrient Substrate	B.O.D. Incubation period, days	B.O.D. of Supernatant Liquor After the Indicated Aeration Time in Hours.						
				0	1/2	1-1/2	3	5	10	24
1	1430	Sterile Sewage	2	109.0	59.5	19.8	12.8	12.0		7.9(4)
			3	138.0	62.0	23.8	15.2	15.0		10.1(4)
			4	164.0	81.0	27.4	17.0	18.0		12.2(4)
			5	186.0	97.5	31.8	22.2	19.7		14.9(4)
2	1632	Synthetic Sewage	2	174.0	85.0	61.0	22.5	12.5		7.0(4)
			3	193.0	114.0	89.0	35.0	23.5		11.2(4)
			4	208.0	141.0	103.0	47.5	39.5		15.3(4)
			5	228.0	157.0	114.0	51.0	38.5		15.8(4)
3	843	Sterile Sewage	2	159.0	67.5	32.2(1)		18.0(2)		8.2
			5	202.0	95.5	45.0(1)		26.4(2)		14.4
			7	242.0	112.0	51.2(1)		27.2(2)		26.0
			11	230.0	100.0	53.7(1)		32.6(2)		28.0
			13	249.0	104.0	63.5(1)		35.8(2)		31.5
4	2644	Sterile Sewage	2	90.0	30.5	19.0	13.0	9.4	9.2	7.2
			5	129.0	40.0	—	15.0	13.0	9.6	12.6
			7	130.0	39.0	15.5	20.7	18.4	10.8	13.9
			10	135.0	61.0	27.7	21.0	16.8	16.0	17.6
			15	133.0	60.5	36.5	36.0	24.6	22.0	21.6*
			20	186.0	79.0	39.7	57.0*	31.8	26.0	34.2*
5	1560	Synthetic Sewage	2	113.0	—	28.2	10.0	18.8	19.6	10.3
			5	154.0	66.0	44.5	27.2	22.6	28.0	15.5
			7	172.0	110.0	47.5	38.5	24.8	36.0	17.3
			10	205.0	122.0	51.7	30.7	35.4	37.8	23.3
			15	215.0	120.0	56.0	44.0	39.2	45.0	29.2
			20	305.0	149.0	68.5	42.7	67.6*	43.2	53.8*
6	3428	Synthetic Sewage	2	113.0	78.5	51.5	20.0	13.8	8.0	13.5
			5	154.0	114.0	78.0	31.2	19.6	16.4	20.8
			7	171.0	121.0	74.0	34.5	25.2	21.8	26.0
			10	205.0	133.0	90.5	40.0	18.8	26.0	35.0
			15	214.0	149.0	107.0	51.5	40.4	23.4	78.9*
			20	305.0	165.0	131.0	100.0*	45.0	29.2	161.0*
7	1632	Sterile Sewage	2	89.9	27.5	27.0	21.2	17.8	11.2	22.6
			5	129.0	42.5	41.0	27.2	18.0	15.4	26.4
			7	130.0	45.0	39.0	34.0	23.8	19.4	28.7
			10	135.0	55.0	53.0	36.7	33.4	19.6	30.0
			15	132.0	—	57.0	52.7	51.0	19.9	36.4
			20	190.0	—	102.0	85.5	69.6	36.0	81.2
8	1056	Sterile Sewage	2	196.0	88.5	60.5	23.2	17.8	14.6	12.1
			5	283.0	118.0	86.0	35.7	28.0	18.2	19.5
			7	288.0	113.0	64.5	42.2	33.6	22.0	22.8
			10	337.0	121.0	72.0	45.7	37.2	40.0	22.7
			15	388.0	138.0	78.2	48.8	46.2	43.8	30.8
			20	436.0	150.0	85.0	65.0	61.6	46.0	38.2
9	2112	Sterile Sewage	2	196.0	56.5	29.5	18.5	17.2	11.6	9.5
			5	210.0	95.0	51.0	28.0	24.2	17.0	17.0
			7	277.0	96.5	64.5	35.7	21.0	21.0	13.5
			10	330.0	110.0	67.5	35.0	26.6	31.0	18.0
			15	389.0	106.0	73.0	39.5	27.2	31.2	23.9
			20	434.0	130.0	77.5	41.7	33.0	36.4	28.5
10	1112	Synthetic Sewage	2	81.3	69.5	44.5	22.5	18.0(3)	8.6	13.6
			5	108.0	85.0	68.0	31.2	23.5(3)	20.6	16.0
			7	123.0	98.0	78.0	36.0	27.6(3)	21.0	19.0
			10	166.0	105.0	90.0	41.7	28.6(3)	30.0	22.4
			15	172.0	—	120.5	48.5	41.0(3)	35.0	24.0
			20	210.0	128.0	102.0	49.7	41.1(3)	36.4	26.3
11	2232	Synthetic Sewage	2	79.6	43.0	19.5	17.5	8.4	15.0	9.6
			5	106.0	66.0	33.5	21.2	25.0	19.0	11.5
			7	122.0	72.0	40.0	23.7	30.4	20.0	12.8
			10	165.0	85.0	35.0	28.7	35.8	22.0	18.1
			15	170.0	88.5	48.0	30.2	32.0	24.0	18.7
			20	207.0	115.0	53.5	37.5	30.0	30.0	24.7

(*) Nitrification indicated. (1) 2 hours. (2) 4 hours. (3) 4-1/2 hours. (4) 22 hours.

TABLE 2.

TOTAL CARBONACEOUS OXYGEN DEMAND (L VALUE) OF SUPERNATANT WHEN NUTRIENT SUBSTRATES ARE AERATED IN THE PRESENCE OF PURE CULTURE ACTIVATED SLUDGE.

Experiment No.	L Value of Supernatant Liquor Initially and After the Indicated aeration time in hours.						
	Initial	1/2	1-1/2	3	5	10	24
1	279	141	48.4	31.5	30.3	- -	20.9(4)
2	384	231	170.0	71.2	50.7	- -	22.5(4)
3	277	124	64.1(1)	- -	36.4(2)	- -	29.3
4	178	66.7	35.9	28.7	23.9	19.9	18.7
5	251	129	64.0	37.5	32.9	45.2	25.7
6	250	167	115.0	48.1	34.3	25.9	34.6
7	179	63.5	59.9	47.0	32.8	25.9	43.4
8	416	163	86.5	59.3	43.7	38.3	32.2
9	414	131	77.3	44.1	34.2	32.6	24.8
10	184	134	107.0	49.7	39.2(3)	31.6	26.8
11	182	101	49.1	37.9	35.1	29.7	20.5

Sterile sewage feed used in Experiments 1, 3, 4, 7, 8, 9.

Synthetic sewage feed used in Experiments 2, 5, 6, 10, 11.

(1) 2 hours. (2) 4 hours. (3) 4-1/2 hours. (4) 22 hours.

TABLE 3.

PERCENTAGE REDUCTION OF TOTAL CARBONACEOUS OXYGEN DEMAND (L VALUE) OF SUPERNATANTS WHEN NUTRIENT SUBSTRATES ARE AERATED IN THE PRESENCE OF PURE CULTURE ACTIVATED SLUDGE.

Experiment No.	L value of initial supernatant P.P.M.	Percentage reduction of L value after indicated aeration time in hours					
		1/2	1-1/2	3	5	10	24
1	279	49.5	82.7	88.7	89.1	- -	92.5(4)
2	384	39.8	55.7	81.5	86.8	- -	94.1(4)
3	277	55.2	76.9(1)	- -	86.9(2)	- -	89.4
4	178	62.5	79.8	83.9	86.6	88.8	89.5
5	251	48.6	71.5	85.1	84.5	82.0	89.8
6	250	33.2	54.0	80.8	86.3	89.6	86.2
7	179	64.5	66.5	73.7	78.3	85.5	75.8
8	416	60.8	79.2	85.7	89.5	90.7	92.3
9	414	68.4	81.3	89.3	91.7(3)	92.1	94.0
10	184	27.2	41.8	73.0	78.7	82.8	85.4
11	182	44.5	73.0	79.2	80.7	83.7	88.7
Ster.Sew. Avg.*	290	60.2	77.7	84.3	87.0	89.3	88.9
Syn. Sew. Avg. ▲	250	38.7	59.8	79.9	83.4	84.5	88.8

(*) Sterile sewage feed used in Experiments 1, 3, 4, 7, 8, 9.

(▲) Synthetic sewage feed used in Experiments 2, 5, 6, 10, 11.

(1) 2 hours. (2) 4 hours. (3) 4-1/2 hours. (4) 22 hours.

TABLE 4.

QUANTITIES OF OXYGEN USED TO OXIDIZE THE NUTRIENT SUBSTRATE WHEN AERATED IN THE PRESENCE OF PURE CULTURE ACTIVATED SLUDGE.

Experiment No.	Initial L value of Supernatant	Milligrams of oxygen used per liter in indicated time in hours					
	P.P.M.	1/2	1-1/2	3	5	10	24
1	379	24.8	47.5	63.8	75.3	- -	111.9(4)
2	384	31.0	79.3	106.9	121.0	- -	158.3(4)
3	277	20.7	54.4(1)	- -	75.5(2)	- -	159.3
4	178	21.3	40.7	56.7	52.0	75.8	107.9
5	251	22.7	56.8	77.8	94.5	105.8	115.3
6	250	12.3	38.3	63.0	83.8	99.5	155.8
7	179	20.4	40.9	46.3	64.4	74.8	103.9
8	416	29.7	63.2	85.7	118.0	166.4	233.0
9	414	48.6	72.4	102.9	130.1	158.4	193.2
10	184	27.0	40.8	53.3	67.2(3)	86.3	95.6
11	182	24.7	47.8	63.6	74.5	83.5	84.2

(1) 2 hours. (2) 4 hours. (3) 4-1/2 hours. (4) 22 hours.

TABLE 5.

PERCENTAGE OF THE TOTAL CARBONACEOUS OXYGEN DEMAND (L VALUE) OF THE NUTRIENT SUBSTRATE OXIDIZED WHEN AERATED IN THE PRESENCE OF PURE CULTURE ACTIVATED SLUDGE.

Experiment No.	Percentage oxidized in the indicated time in hours					
	1/2	1-1/2	3	5	10	24
1	8.9	17.0	22.9	27.0	- -	40.1(4)
2	8.1	20.7	27.8	31.5	- -	41.2(4)
3	7.5	19.6(1)	- -	27.3(2)	- -	57.5
4	12.0	22.9	31.9	29.2	42.6	60.6
5	9.0	22.6	31.0	37.6	42.2	45.9
6	4.9	15.3	25.2	33.5	39.8	62.3
7	11.4	22.8	25.9	36.0	41.8	58.0
8	7.1	15.2	20.8	28.4	40.0	56.0
9	11.7	17.5	24.9	31.4	38.3	46.7
10	14.7	22.2	29.0	36.5(3)	46.9	52.0
11	13.6	26.3	34.9	40.9	45.9	46.3

(1) 2 hours. (2) 4 hours. (3) 4-1/2 hours. (4) 22 hours.

TABLE 6.

NET PERCENTAGE OF THE TOTAL CARBONACEOUS OXYGEN DEMAND (L VALUE) OF THE NUTRIENT SUBSTRATE THAT IS REMOVED BY ADSORPTION AND SYNTHESIS WHEN AERATED IN THE PRESENCE OF PURE CULTURE ACTIVATED SLUDGE.

Experiment No.	Nutrient substrate Used	Net percentage removed by adsorption and synthesis in indicated time in hours					
		1/2	1-1/2	3	5	10	24
1	Sterile Sewage	40.6	65.7	65.8	62.1	- -	52.4
3	"	47.7	57.3(1)	- -	59.6(2)	- -	31.9
4	"	50.5	56.9	52.0	57.4	46.2	28.9
7	"	53.1	43.7	47.8	42.3	43.7	17.8
8	"	53.7	64.0	64.9	61.1	50.7	36.3
9	"	56.7	63.8	64.4	60.3	53.8	47.3
Mean	Sterile Sewage	50.4	58.6	59.0	57.1	48.6	35.8
2	Synthetic Sewage	31.7	35.0	53.7	55.3	- -	52.9(4)
5	"	39.6	51.9	54.1	46.9	39.8	43.9
6	"	28.3	38.7	55.6	52.8	49.8	23.9
10	"	12.5	19.6	44.0	42.2(3)	35.9	33.4
11	"	30.9	46.7	44.3	39.8	37.8	42.4
Mean	Synthetic Sewage	28.6	38.4	50.3	47.4	40.8	39.3

(1) 2 hours. (2) 4 hours. (3) 4-1/2 hours. (4) 22 hours.

TABLE 7.

PERCENTAGE OF THE TOTAL CARBONACEOUS OXYGEN DEMAND REDUCTION OF THE SUBSTRATE ACTUALLY OXIDIZED WHEN AERATED WITH PURE CULTURE ACTIVATED SLUDGE.

Experiment No.	Substrate Feed Used	Percentage oxidized in the indicated aeration time in hours					
		1/2	1-1/2	3	5	10	24
1	Sterile Sewage	18.0	20.6	25.8	30.3	- -	43.4(4)
3	"	13.6	25.5(1)	- -	31.4(2)	- -	64.3
4	"	19.2	28.7	38.0	33.7	48.0	67.7
7	"	17.7	34.3	35.1	46.0	48.9	76.5
8	"	11.7	19.2	24.3	31.7	44.1	60.7
9	"	17.1	21.5	27.9	34.2	41.6	49.7
Mean	Sterile Sewage	16.2	25.0	30.2	34.6	45.6	57.2A
2	Synthetic Sewage	20.4	37.2	34.1	36.3	- -	43.8(4)
5	"	18.5	30.3	36.4	44.5	51.5	51.1
6	"	14.8	28.3	31.2	38.8	44.4	72.3
10	"	54.0	53.1	39.7	46.4(3)	56.6	60.9
11	"	30.6	36.0	44.1	50.7	54.8	52.2
Mean	Synthetic Sewage	21.1*	33.0*	37.1	43.3	51.8	56.1

(A) Excluding No. 7. (*) Excluding No. 10.

(1) 2 hours. (2) 4 hours. (3) 4-1/2 hours. (4) 22 hours.

TABLE 8.

B.O.D. OF SUPERNATANTS WHEN NUTRIENT SUBSTRATES ARE AERATED IN THE PRESENCE OF NORMAL ACTIVATED SLUDGE.

Exp. No.	Susp. Solids p.p.m.	Nutrient Substrate	B.O.D. Incubation Period, Days	B.O.D. of Supernatant Liquor After the Indicated Aeration Time in Hrs.						
				Initial 0	1/2	1-1/2	3	5	10	24
1	4610	Set.Sewage	3	132	32.4	15.1	8.8	9.2	5.8	4.5
			5	162	42.8	24.0	13.0	10.7	8.0	11.7
			7	168	49.6	32.6	17.1	13.0	9.0	13.6
			10	200	62.0	40.0	21.4	15.8	14.0	13.8
2	1000	Settled Sewage	3	189	124.0	73.6	56.5		19.3	10.5
			5	251	152.0	82.0	84.0		29.0	12.0
			7	296	173.0	111.0	188.0		32.8	12.6
			10	394	209.0	150.0	139.0		41.1	21.1
3	2448	Settled Sewage	2	96.6	24.8	15.6	6.2	6.1	5.0	6.9
			5	142.0	42.0	28.3	17.4	6.8	8.8	6.0
			7	155.0	48.0	29.1	17.0		13.8	10.8
			10	171.0	123.0	77.3	62.5	50.0	21.4	
			15	244.0	169.0	132.0	94.0	64.8	40.6	25.2
			20	352.0	189.0	137.0		69.6	34.6	25.0
4	2504	Clarified Sewage	2	47.6	11.4	10.8	2.3	2.0	3.5	8.3
			5	67.0	19.6	24.9	6.4	7.8	6.0	8.7
			7	77.4	61.6	40.0	25.5	15.0	15.2	13.0
			10	80.6	59.0	60.6	38.0	33.5	15.9	
			15	132.5	135.0	88.6	75.9	51.8	23.5	20.9
			20	186.6	155.0	109.2		54.0	24.5	19.8
5	2812	Synthetic Sewage	2	160	111.0	95.2	80.0	70.0	26.9	14.4
			5	257	172.0	161.0	140.0	124.0	62.5	22.0
			7	297	206.0	188.0	182.0	145.0	86.2	32.5
			10	322	253.0	234.0	190.0	195.0	119.4	58.9
			15	336	390.0	323.0		221.0	152.0	75.2
			20	384	449.0				157.0	80.7
6	2676	Synthetic Sewage	2	182	162.0	112.0	95.0	74.0	27.6	6.7
			5	268	220.0	171.0	149.0	123.0	47.6	13.0
			7	280	239.0	195.0	176.0	168.0	55.4	12.0
			10	311	260.0	220.0	209.0	246.0	74.8	18.5
			15	335	399.0	393.0	298.0	264.0	142.0	49.7
			20	542	465.0	402.0	377.0	308.0	167.0	69.0

5	2612	Synthetic Sewage	2	182	162.0	112.0	95.0	74.0	27.6	6.7
			5	257	172.0	161.0	140.0	124.0	62.5	22.0
			7	297	206.0	188.0	182.0	145.0	86.2	32.5
			10	322	253.0	234.0	190.0	195.0	119.4	58.9
			15	336	390.0	323.0		221.0	152.0	75.2
			20	384	449.0				157.0	80.7
6	2676	Synthetic Sewage	2	182	162.0	112.0	95.0	74.0	27.6	6.7
			5	268	220.0	171.0	149.0	123.0	47.6	13.0
			7	280	239.0	195.0	176.0	168.0	55.4	12.0
			10	311	260.0	220.0	209.0	246.0	74.8	18.5
			15	335	399.0	393.0	298.0	264.0	142.0	49.7
			20	547	465.0	402.0	377.0	309.0	163.0	62.0
7	2268	Settled Sewage	2	159	60.0	23.8(1)		13.6(2)	9.1	4.6
			5	235	96.0	36.8(1)		21.7(2)	10.3	10.5
			7	250	110.0	46.0(1)		31.7(2)	17.0	11.3
			10	264	128.0	92.0(1)		58.0(2)	32.1	9.3
			15	282	227.0	162.0(1)		91.8(2)	35.0	27.2
			20	381	276.0	190.0(1)		97.1(2)	44.9	28.5
8	3564	Settled Sewage	2	53.7	18.2	8.6(1)		14.8(2)	6.0(3)	3.0
			5	96.8	27.5	10.8(1)		20.0(2)	10.9(3)	10.0
			7	106.0	35.7	22.4(1)		18.6(2)	14.0(3)	11.0
			10	122.0	42.5	37.4(1)		35.0(2)	13.0(3)	13.0
			15	125.0	52.0	33.2(1)		31.4(2)	18.5(3)	14.9
			20	124.0	118.5	46.2(1)		30.4(2)	18.7(3)	15.0
9-S1	132	Settled Sewage	2	60.6	51.5	37.5(1)		26.0(2)		10.1
			5	114.3	80.0	59.5(1)		31.7(2)		13.6
			7	164.3	101.0	60.5(1)		35.0(2)		19.3
			10	165.5	105.0	72.0(1)		71.2(2)		20.5
			15	216.3	100.0	89.5(1)		60.7(2)		34.6
			20	264.5	158.0	115.0(1)		97.5(2)		70.3
9-S3	760	Settled Sewage	2	129	10.0	13.5(1)				6.2
			5	234	32.0	46.0(1)		26.0(2)		17.0
			7	200	78.0	66.0(1)		38.5(2)		18.0
			10	219	80.0	40.5(1)		21.0(2)		21.8
			15	285	107.0	25.0(1)		64.5(2)		
			20	415	253.0	138.0(1)		169.0(2)		
9-S4	1188	Settled Sewage	5	57.5	24.0	13.6(1)		11.8(2)		13.4
			7	63.7	51.0	14.0(1)		22.6(2)		15.5
			10	64.5	40.0	24.0(1)		21.0(2)		21.7
			15	96.8	42.5	16.8(1)				
			20	126.0	76.5					
9-S5	1462	Settled Sewage	2	54.5	30.5	10.6(1)		9.8(2)		5.2
			5	125.0	44.5	15.6(1)		11.4(2)		9.4
			7	140.0	52.5	21.0(1)		15.6(2)		16.2

		Sewage	5	331						
			7	200	78.0	66.0(1)		38.5(2)		18.0
			10	219	80.0	40.5(1)		21.0(2)		21.8
			15	285	107.0	25.0(1)		64.5(2)		
			20	415	253.0	138.0(1)		169.0(2)		
9-S4	1188	Settled Sewage	5	57.5	24.0	13.6(1)		11.8(2)		13.4
			7	63.7	51.0	14.0(1)		22.6(2)		15.5
			10	64.5	40.0	24.0(1)		21.0(2)		21.7
			15	96.8	42.5	16.8(1)				
			20	126.0	76.5					
9-S5	1462	Settled Sewage	2	54.5	30.5	10.6(1)		9.8(2)		5.2
			5	125.0	44.5	15.6(1)		11.4(2)		9.4
			7	140.0	52.5	21.0(1)		15.6(2)		16.2
			10	148.0	65.5	24.2(1)		26.6(2)		24.0
			15	148.0	93.0	43.0(1)		35.8(2)		
			20	177.0	94.0	62.0(1)				
9-S6	1448	Settled Sewage	2	51.9	16.0	12.7(1)		18.8(2)		3.0
			5	83.6	31.5	23.2(1)		22.0(2)		7.5
			7	99.6	26.5	24.0(1)		21.0(2)		9.8
			10	113.0	40.5	42.5(1)		24.2(2)		
			15	121.0	46.5			44.8(2)		11.2
			20	129.0	66.0			52.8(2)		15.1
10-S8	2920	Settled Sewage	2	135.0	10.0	13.0(1)		9.0(2)		8.0
			5	182.0	17.5	16.5(1)		16.8(2)		13.4
			7	225.0	29.0	26.2(1)		23.4(2)		15.0
			10	266.0	29.0	24.2(1)		27.2(2)		17.8
			15	306.0	55.5	29.2(1)		30.2(2)		16.8
			20	336.0	76.0	35.2(1)		31.2(2)		22.8
10-S9	2864	Settled Sewage	2	147	18.5(4)		17.8	8.8		8.5
			5	144	25.5(4)		29.0	14.6		12.7
			7	231	34.5(4)		30.5	22.2		14.4
			10	228	36.0(4)		32.0	23.6		15.5
			15	231	39.0(4)		37.0	27.4		19.4
			20	251	51.5(4)		41.5	26.8		18.9

(1) 2 hours. (2) 4 hours. (3) 12 hours. (4) 1 hour.

TABLE 9.

TOTAL CARBONACEOUS OXYGEN DEMAND (L VALUE) OF SUPERNATANT WHEN NUTRIENT SUBSTRATES ARE AERATED IN THE PRESENCE OF NORMAL ACTIVATED SLUDGE.

Experiment No.	Activated Sludge Suspended Solids P. P. M.	L Value of Supernatant Liquod Initially and After the Indicated Time in Hours.						
		0	1/2	1-1/2	3	5	10	24
1	4610	234	64.6	37.6	20.4	17.0	12.5	14.6
2	1000	388	230.0	144.0	130.0		42.0	19.4
3	2448	214	62.9	40.0	21.1	13.2	14.6	13.7
4	2504	103	50.6	45.8	22.4	18.2	15.2	14.5
5	2812	385	273.0	247.0	215.0	184.0	90.8	37.3
6	2676	395	337.0	260.0	232.0	197.0	74.2	18.2
7	2268	334	150.0	69.4(2)		43.2(3)	24.2	13.1
8	3564	135	47.0	34.8(2)		32.4(3)	18.0(4)	16.0
9-S1	182	189	121.0	87.4(2)		60.5(3)		23.6
9-S3	760	296	74.0	51.4(2)		36.5(3)		22.1
9-S4	1188	83.8	46.8	20.4(2)		22.9(3)		21.0
9-S5	1462	165	76.4	29.8(2)		25.9(3)		18.7
9-S6	1448	128	43.1	36.4(2)		36.5(3)		10.7
9-S8	2920	305	35.7	29.8(2)		27.9(3)		19.4
9-S9	2864	287	43.8		40.7	25.8(3)		19.3

Settled sewage feed used in Experiments 1, 2, 3, 7, 8 and 9.

Clarified sewage feed used in Experiment 4.

Synthetic sewage feed used in Experiments 5 and 6.

(2) 2 hours. (3) 4 hours. (4) 12 hours.

TABLE 10.

PERCENTAGE REDUCTION OF TOTAL CARBONACEOUS OXYGEN DEMAND (L VALUE) OF SUPERNATANTS WHEN NUTRIENT SUBSTRATES ARE AERATED IN THE PRESENCE OF NORMAL ACTIVATED SLUDGE.

Experiment No.	L value of Initial Supernatant	Percentage Reduction of L Value After Indicated time in Hours					
		1/2	1-1/2	3	5	10	24
1	234	72.4	83.9	91.4	92.7	94.7	93.8
2	388	40.7	62.9	66.5		89.2	95.0
3	214	70.6	81.3	90.1	93.8	93.2	93.6
4	103	50.9	55.5	78.3	82.3	85.2	85.9
5	385	29.1	35.8	44.2	52.2	76.4	90.3
6	395	14.7	34.2	41.3	50.1	81.2	95.4
7	334	55.1	79.2(2)		87.1(3)	92.8	96.1
8	135	65.2	74.2(2)		76.0(3)	86.7(4)	88.1
9-S1	189	36.0	53.8(2)		68.0(3)		87.6
9-S3	296	75.0	82.6(2)		87.7(3)		92.5
9-S4	83.8	44.2	75.7(2)		72.7(3)		74.9
9-S5	165	53.7	81.9(2)		84.3(3)		88.7
9-S6	128	66.3	71.6(2)		71.5(3)		91.6
9-S8	305	88.3	90.2(2)		90.9(3)		93.6
9-S9	287	84.7		85.8	91.0(3)		93.3

Settled sewage used in Experiments 1, 2, 3, 7, 8 and 9.

Clarified sewage used in Experiment 4.

Synthetic sewage used in Experiments 5 and 6.

(2) 2 hours. (3) 4 hours. (4) 12 hours

TABLE 11.

QUANTITIES OF OXYGEN USED TO OXIDIZE THE NUTRIENT SUBSTRATE WHEN AERATED IN THE PRESENCE OF NORMAL ACTIVATED SLUDGE

Experiment No.	Initial L Value of Supernatant	Milligrams of oxygen used per liter in indicated time in hours.					
		1/2	1-1/2	3	5	10	24
1	234	13.9	46.9	81.0	134.2	161.5	173.8
2	388	3.9	26.7	47.7		122.2	176.3
3	214	8.3	24.0	50.4	75.1	101.7	
4	103	22.0	44.1	80.7	107.3	124.4*	
5	385	8.2	36.6	54.1	71.4	121.4	130.0
6	395	18.8	45.5	71.0	89.8	139.0	184.6
7	334	7.1	41.2(2)		88.7(3)	145.6	189.8
8	135	25.2	49.7(2)		106.7(3)	155.9(4)	213.7*
9-S1	189	0.0	7.3(2)		16.0(3)		46.6
9-S3	296	16.4	39.0(2)		49.0(3)		86.4
9-S4	83.8	0.4	10.0(2)		13.8(3)		16.4
9-S5	165	21.2	34.8(2)		42.6(3)		121.7
9-S6	128	20.5	36.5(2)		45.6(3)		94.6
9-S8	305	47.0(1)		84.8	92.8		89.2
9-S9	287	29.1(1)		137.3	158.6		226.4*

Settled sewage used in Experiments 1, 2, 3, 7, 8 and 9.

Clarified sewage used in Experiment 4.

Synthetic sewage used in Experiment 5 and 6.

(*) Substrate was being nitrified.

(1) 1 hour. (2) 2 hours. (3) 4 hours. (4) 12 hours

TABLE 12.

PERCENTAGE OF THE TOTAL CARBONACEOUS OXYGEN DEMAND (L VALUE) OF THE NUTRIENT SUBSTRATE OXIDIZED WHEN AERATED IN THE PRESENCE OF NORMAL ACTIVATED SLUDGE.

Experiment No.	Percentage Oxidized in the Indicated Time in Hours					
	1/2	1-1/2	3	5	10	24
1	5.9	20.0	34.6	57.4	69.0	74.3
2	1.0	6.9	12.3		31.5	45.4
3	3.9	11.2	23.6	35.1	47.5	
4	21.4	42.8	78.3	104.1	120.8*	
5	2.1	9.5	14.1	19.5	31.5	33.8
6	4.8	11.5	18.0	22.7	35.2	46.7
7	2.1	12.3(2)		26.6(3)	43.6	56.8
8	18.7	36.8(2)		79.0(3)	115.5(4)	158.3*
9-S1	0.0	3.9(2)		8.5(3)		24.7
9-S3	5.5	13.2(2)		16.6(3)		29.2
9-S4	0.5	11.9(2)		16.5(3)		19.5
9-S5	12.8	21.1(2)		25.8(3)		73.8
9-S6	16.0	28.5(2)		35.6(3)		73.9
9-S8	15.4(1)		27.8	30.4		29.2
9-S9	10.1(1)		47.8	55.2		78.9*

Settled sewage used in Experiments 1, 2, 3, 7, 8 and 9.

Clarified sewage used in Experiment 4

Synthetic sewage used in Experiments 5 and 6.

(*) Substrate was being nitrified.

(1) 1 hour. (2) 2 hours. (3) 4 hours. (4) 12 hours.

TABLE 13.

NET PERCENTAGE OF THE TOTAL CARBONACEOUS OXYGEN DEMAND (L VALUE) OF THE NUTRIENT SUBSTRATE THAT IS REMOVED BY ADSORPTION AND SYNTHESIS WHEN AERATED IN THE PRESENCE OF NORMAL ACTIVATED SLUDGE.

Experiment No.	Nutrient Substrate Used	Net Percentage Removed by Adsorption and Synthesis in Indicated Time in Hours.					
		1/2	1-1/2	3	5	10	24
1	Settled Sewage	66.5	63.9	56.8	35.3	25.7	19.5
2	"	39.7	56.0	54.2		57.7	49.6
3	"	66.7	70.1	56.5	58.7	45.7	
7	"	53.0	66.9(2)		60.5(3)	49.2	39.3
8	"	46.5	37.4(2)		0.0(3)	0.0(4)	0.0
4	Clarified Sewage	29.5	12.7	0.0	0.0	0.0	0.0
5	Synthetic Sewage	27.0	26.3	30.1	33.7	44.9	56.5
6	"	9.9	22.7	23.3	37.4	46.0	48.7
9-S1	Settled Sewage	36.0	49.9(2)		59.5(3)		62.9
9-S3	"	69.5	69.4(2)		71.1(3)		63.3
9-S4	"	43.7	63.9(2)		56.2(3)		55.4
9-S5	"	40.5	60.8(2)		58.5(3)		14.9
9-S6	"	50.3	43.1(2)		35.9(3)		17.7
9-S8	"	72.9(1)		62.7	60.5(3)		64.4
9-S9	"	74.6(1)		38.0	35.8(3)		14.4

(1) 1 hour. (2) 2 hours. (3) 4 hours. (4) 12 hours.

TABLE 14.

PERCENTAGE OF THE TOTAL CARBONACEOUS OXYGEN DEMAND REDUCTION OF THE SUBSTRATE ACTUALLY OXIDIZED WHEN AERATED WITH NON-NITRIFYING ACTIVATED SLUDGE.

Experiment No.	Percentage oxidized in indicated time in hours.					
	1/2	1-1/2	3	5	10	24
1	8.15	23.8	37.9	61.9	72.9	79.2
2	2.46	11.0	18.5		35.3	47.8
3	5.52	13.8	26.2	37.4	51.0	
5	7.22	26.5	31.3	35.4	41.2	37.4
6	32.7	33.6	43.6	45.3	43.3	49.0
7	3.81	15.5		30.5	47.0	59.1
9-S4	1.13	15.7		27.7		26.0
9-S5	23.8	25.8		30.3		83.2
9-S6	18.1	31.6		39.2		75.0
Mean	11.4	21.9	31.6	37.9	48.4	57.6

Settled sewage used in Experiments 1, 2, 3, 7 and 9.

Synthetic sewage used in Experiments 5 and 6.